FEASIBILITY OF RADAR DETECTION OF A EUROPAN OCEAN FROM AN ORBITING SPACECRAFT. C.F. Chyba[1], S.J. Ostro[2], and B.C. Edwards[3]. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 85721; chyba@lpl.arizona.edu. [2]Jet Propulsion Laboratory, MS 300-233, Pasadena, CA 91109-8099. [3]Los Alamos National Laboratory, MS D436, Los Alamos, NM 87544.

The original reconnaissance by Voyager and new results from Galileo suggest the possibility of a liquid water ocean beneath the ice of Jupiter's moon Europa [1]. Some current tidal heating models favor the existence of an ocean a few tens of km beneath the surface, and perhaps as little as 1 km beneath young faults [2]. The search for and characterization of a Europan ocean via remote sensing is the prerequisite Europa mission, setting the stage for all subsequent exploration [3].

Ice penetrating radar (IPR) may offer the best hope for a direct detection of a Europan subsurface ocean from an orbiting spacecraft [4]. Because the electrical properties of rock, ice, and liquid water differ greatly, detection of a discrete ice/water or ice/rock boundary beneath the ice is possible. Here we demonstrate that a 6-meter-wavelength radar could detect an ice-water interface ~20 km beneath the surface, given reasonable assumptions about the properties of Europan ice.

Terrestrial radar sounding. Extensive radar sounding of Greenland and polar ice sheets, sea ice, and glaciers provide a terrestrial baseline [5]. Lakes have been detected and characterized beneath as much as 4 km of polar ice [6]. Because attenuation in ice decreases exponentially with temperature [7], it may be possible to penetrate much deeper into Europan ice than in the terrestrial analogues.

Earth-based radar observations of Europa. Radar studies during the past 20 years have established that at 3.5- and 13-cm wavelengths both Europa's average total-power radar albedo (2.7) and the ratio of echo power in the same sense of circular polarization as transmitted to the opposite sense (1.6) exceed those of any other radar-detected solar system object [8]. This implies that the uppermost few meters of Europa's surface is very clean ice possessing density variations at scales that multiply scatter 3.5 to 13 cm waves [9]. At 70 cm, Europa's albedo drops by at least an order of magnitude [10], suggesting that wavelengths no shorter than several meters are required for radar sounding. At the same time, decametric radiation from Jupiter increases rapidly at frequencies below about 50 MHz [11]. A choice of free-space wavelength of 6 m (50 MHz) is a good compromise for sounding Europa's subsurface.

Attenuation in bulk ice. We model IPR signal attenuation due to dielectric absorption in Europa's ice, and that due to impurities in the ice. Attenuation is $0.129 \div e_r f [\div(1+\tan^2 d) -1]^{1/2}$ dB/m [5], where $\tan d = e_i/e_r$, e_r and e_i are the real and imaginary parts of the dielectric constant, respectively, and f is the frequency in MHz. Data ranging from -1 to -60 C [12] show that attenuation increases dramatically at wavelengths below about 1 m. Moreover, attenuation falls off rapidly as a function of temperature.

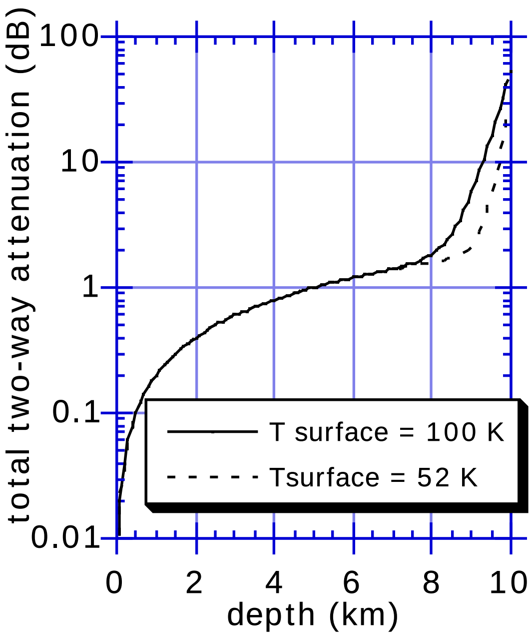
Temperature dependence. We interpolate the existing data to 6 meters and extrapolate them to Europan surface temperatures (~100 K). This requires modeling how the dielectric constants vary with temperature. For a regular dielectric such as ice, e_r and e_i vary with absolute temperature T and frequency w according to the Debye equation; e_i and therefore attenuation is proportional to exp(-E/kT), where E is an activation energy [7]. The formulae resulting from fitting the existing temperature data with a Debye equation provide a sound physical basis for the extrapolation of e_r and e_i to lower temperatures, giving attenuation in ice as a function of T.

The role of impurities. To gain an appreciation of how impurities in Europan ice might affect IPR sounding, we model the addition of "dirt" (as well as other impurities, such as salts) to the ice. We take the dielectric properties of "dirt" to be those typical of rock, meteorites, or powdered rock [13,14]. With these values, pure "dirt" has an attenuation of about 0.1 dB/m, an order of magnitude higher than that found for dry salt deposits. Impurity concentrations in ice at Europa's surface of more than a few weight-percent are ruled out by the strength of ice absorption bands in reflection spectra; the concentration of impurities could be much less than this upper limit [15]. Our initial modeling mixes "dirt" into Europan ice at the 0.1% level.

There is a large body of work on the dielectric properties of mixtures. Here we use Lichtenecker's formula [14], which holds for unordered mixtures. When the volume fraction of the impurity is small and $e_i << e_r$, the two components contribute linearly to net attenuation, weighted by their volume fractions. At the 0.1% level, "dirt" impurities give a constant 0.1 dB/km attenuation added to that due to the ice. For low concentrations, the effect this impurity scales linearly with volume concentration.

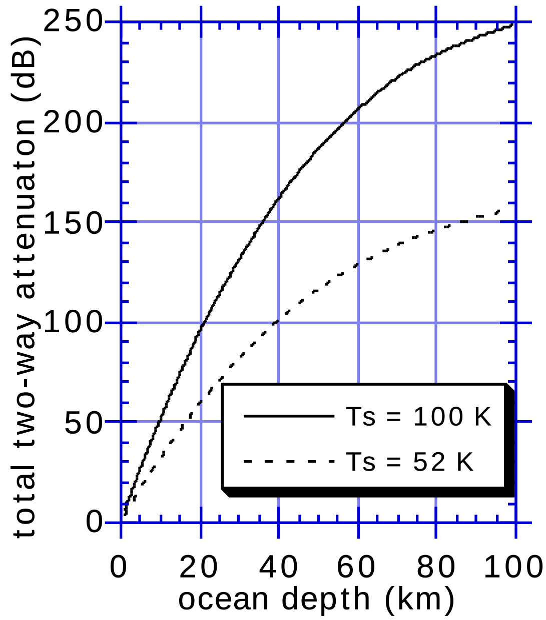
Temperature profile of Europa's ice layer. Because attenuation in ice is so strongly temperature dependent, the temperature profile of Europan ice is important for modeling attenuation with depth. The ice temperature at the base of the ice is obtained by setting it equal to the melting temperature at the pressure appropriate to that depth. Calculations yield a Europan surface-averaged temperature of 100 K, and a mean temperature of 52 K at the poles [16]. Taking into account the temperature dependence of the thermal conductivity of ice [7], we follow ref. 16 and find as an initial approximation that T at depth z will be given by $T(z)=T_s\exp(z/h)$. Here $h=b/\ln(T_b/T_s)$, b is the depth of the base of the ice, and T_s and T_b are the temperatures at the surface and base of the ice, respectively.

Fig. 1. 50 MHz attenuation for ocean10 km below surface



Initial results. For these assumptions, Fig.. 1 shows the two-way attenuation of 50 MHz radar propagating into 10 km of ice (+0.1% "dirt") underlain by an ocean at 272 K, for surface temperatures of 100 K and 52 K. Total two-way attenuations through the ice are about 50 dB and 30 dB, respectively. Fig. 2 shows total two-way attenuations for the analogous 0.1% dirty ice layers ranging from 1 to 100 km thick. Taking into account $1/r^2$ losses, interface reflection and transmission losses, reasonable antenna bandwidths (2 MHz) and gain (10), and noise from Jupiter and the galactic background, we find that an IPR aboard a spacecraft orbiting Europa at an altitude of 30 km should be able to detect a water/ice interface about 15 km below the surface for T_s=100 K, and about 25 km below the surface for T_s=52 K, (depths corresponding to about 70 dB of two-way attenuation). This is consistent with radar probing of Greenland ice, which has been imaged to depths corresponding to two-way attenuations of 80 dB (or about 3 km depth in the comparatively warm Greenland ice) [5]. Radar sounding from an orbiting spacecraft appears to be a viable direct method for detecting a Europan ocean.

Fig 2. 50 MHz attenuation vs. depth of ocean



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